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Impulse Drying of Board Grades: Converting Trials

D.I. Orloff, P.M. Phelan, J. Challas

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IMPULSE DRYING OF BOARD GRADES: CONVERTING TRIALS

David I. Orloff
Professor and Director, Engineering Division
Institute of Paper Science and Technology
500 10th Street N.W., Atlanta, GA 30318

Paul M. Phelan
Associate Scientist, Engineering Division
Institute of Paper Science and Technology
500 10th Street N.W., Atlanta, GA 30318

James Challas
Innovative Development Systems, Inc
Consultant
5084 Night Hawk Drive
Golden Canyon, AZ 85219

ABSTRACT

Reels of linerboard produced on a pilot paper machine were converted on a commercial corrugator and the results compared to those obtained for a commercial liner. The pilot paper machine-produced liner included single-felted wet pressed liner as well as impulse dried liner.

The converting trials were conducted at the Stone Container plant in Keokuk, Iowa, in October 1998. The flexo-folder-gluer operation proceeded quite smoothly. In addition, there were no problems encountered during die cutting and no score cracking problems were noted. Finished containers were tested at the Institute for edge crush, flexural stiffness, pin adhesion, and box compression strength.

The performance of the impulse dried liner was compared to the single-felted wet pressed control as well as the commercial sample. The comparisons demonstrated that impulse dried linerboard increased ECT and box compression strength by as much as 10%. Hence, it is anticipated that impulse drying could be used to reduce fiber use by about 10%, while maintaining strength properties.

EXPERIMENTAL

The plan was to convert the Beloit 0.76 m (30 inch) wide rolls [1] on a commercial corrugator to make combined board. Each run would produce a minimum of 1000 blanks, 1.52 m (60 inches) long and 0.69 m (27 inches) wide, from which 750 would be printed and converted into shipping containers and 250 blanks would be die cut and not printed. The resulting single-wall container would be 0.38 m (15 inches) long, 0.36 m (14 inches wide), and 0.30 m (12 inches) high.

A printing plate was selected for printing comparisons. The print copy included an Institute of Paper Science and Technology letterhead logo that was enlarged to 0.15 m (6 inches) in diameter. It also included conventional halftones of Edgar Allen Poe; lines, from 1/2 point to 8 point; portions of UPC and shipper UPC; and a heliograph of a child car seat.

A number of container plants were contacted to determine if they could run five sets of narrow 0.76 m (30 inch) wide rolls to produce combined board, as well as print and produce containers from impulse dried 161 g/m^2 (33#) kraft linerboard made on Beloit pilot paper machine. One set of 161 g/m^2 (33#) commercial kraft liner in any roll of their plant inventory would also be run. Each of the six runs would have a maximum of 3048 lineal meters (10,000 lineal feet). If the runs on the corrugator went smoothly, it could be shortened to 1524 lineal meters (5000 lineal feet).

The results from the inquiries were not encouraging at first; however, we eventually were fortunate to receive a positive response from the Stone Container plant in Keokuk, Iowa. Converting trials were conducted in October 1998.

Tables I through III show specific details of the three unit operations performed at the box plant. The corrugator crew had been fully informed and coached by the plant manager in advance of the run and the implementation of the actual run went very smoothly. The single-facer and double-backer splicers were loaded with appropriate rolls in the planned sequence and when 305 lineal meters (1000 lineal feet) had been produced, the splicers automatically spliced in the next rolls in the sequence. The commercial rolls of 161 g/m^2 (33#) liner were run as a wider roll, 1.689 m (66.5 inch), from the plant inventory. The corrugating medium, 1.686 m (66.375 inch) wide, came from the same lot as the 0.759 m (29.875 inch) wide rolls used for the Beloit pilot liner.

Table IV identifies the liner used in each of the corrugator cases. Corrugator case 1 was conducted with commericial linerboard. Corrugator cases 2A, 2B, 4, and 6 used impulse-dried liner while cases 3 and 5 used the single-felted wet pressed control. The same medium was used for all corrugator cases. Note that case 2A and 2B were produced from different reels produced at the same nominal conditions. Table V shows some pertinent physical properties of the liner and medium used in each case [1]. Note that the impulse dried cases had higher strength, lower caliper, and lower roughness than the wet pressed controls. As noted in the previous paper [1], part of the strength increase is due to increased refining.

The flexo-folder-gluer operation also proceeded quite smoothly after adjusting for proper ink coverage and printing pressure on all six sets of blanks. Finished containers were placed on pallets, shrink wrapped for final shipment, and tested at the Institute.

No problems were observed in the die cutting operation, and no score cracking problems noted in MD, CD, or angle scores.

RESULTS

Combined board and boxes produced for each case were numbered in the order of corrugating prior to the initiation of testing. Four sequential sets of samples were taken from each of the cases, resulting in a total of 28 sample sets.

Lane and Sequence Effects

Lane-specific testing of the liner demonstrated a CD profile in each of the reels produced on the Beloit pilot machine. The center lane typically was found to exhibit lower strength. It was therefore important to test the combined board in both the center and edge lanes for edge crush, caliper, and pin adhesion. The results of these tests are plotted versus corrugator sequence in Figures 1 through 4.

In Figure 1 the edge crush as measured in the center lane was typically lower than that measured on the edges for cases 2A through 6. This is consistent with the lower STFI compression strength, ring crush, and higher MD/CD ratio of the center lane of the liner. The edge crush of case 1, the commercial control, was position independent, as expected.

In Figure 2 the caliper of the combined board is reported for both the center and edges of the samples. There was a slight tendency for the center to be of lower caliper than the edges.

Single-facer pin adhesion data is reported in Figure 3. There was no observed bias regarding test position as the results in the center are similar to those on the edges. Double-backer pin adhesion data is reported in

Figure 4. Here, the pin adhesion strength in the center was typically higher than at the edges. This was also true for the commercial control. Hence, it is probable that this bias was due to converting equipment rather than the liner.

Figure 5 shows the flexural stiffness of the combined board as measured in both the MD and CD directions. Due to the size of the test specimen, only the center was tested.

Figure 6 shows the peak load as measured during top-to-bottom box compression testing. Note that case 6 could not be included as we only made combined board blanks and did not make boxes in this case. Figure 7 shows the deflection at peak load as measured during the box compression testing.

Case Effects

In Figures 8 through 14, the four sequential sets in each case are pooled together to obtain average properties per case. Figure 8 shows that the highest edge crush values were obtained for cases 1, 2A, 2B, and 4, while the lowest edge crush values were obtained in cases 3, 5, and 6.

Figure 9 shows that the commercial liner yielded combined board with the highest caliper, while board made from the pilot produced reels were of consistently lower caliper. It was observed that the combined board from the pilot rolls had visible flute crushing, indicating that too much pressure was applied at the double backer.

Figure 10 shows that the highest single-facer pin adhesion values were obtained for cases 3 and 5 where the single-felted wet pressed liner was utilized. Pin adhesion for the impulse dried cases were lower but consistent with that obtained using the commercial liner, case 1. Figure 11 shows that the double-backer pin adhesion for board made from the pilot-produced liner was at least as strong as that obtained from the commercial sample, case 1.

Figure 12 shows that the flexural stiffness was increased when the liner was impulse dried. Further analysis (see below) shows that this was related to increases in Young's modulus of the impulse dried liner.

Figure 13 shows an improvement in box compression strength for the impulse dried cases 2A, 2B and 4 as compared to the wet pressed control cases 3 and 5. The impulse dried cases are a least as strong as the commercial control. Boxes made from liner impulse dried at the highest temperature were superior in strength to those made from the wet pressed control as well as the commercial control.

Figure 14 shows that box deflection at peak load was fairly independent of case.

Table VI shows the average edge crush, combined board caliper, and single-facer and double-backer pin adhesions for each case. Table VII shows the percentage change for each of these as compared to the corresponding wet-pressed control. It is observed that impulse drying resulted in as much as a 10.6% increase in edge crush, a decrease in single-facer pin adhesion of as much as 27.3%, and an increase in double-backer pin adhesion of as much as 9.5%.

Table VIII shows the average peak load from top-to-bottom, end-to-end, and side-to-side box compression testing, as well as the MD and CD flexural stiffness of the combined board. Table IX reports the percent change of these properties as compared to the appropriate wet pressed control. Impulse drying resulted in as much as a 10.3% increase in top-to-bottom box compression strength.

Visual inspection of the printed boxes showed significant improvement to print coverage. Impulse dried samples had superior print quality to boxes made from the wet pressed control liners as well as those made from the commercial liner.

DISCUSSION

Box Compression Strength

In 1963 McKee [2] published an equation which could be used to predict box compression strength as a function of edge crush strength, flexural stiffness, and box perimeter.

The McKee equation is,

$$P = 0.3508\ (P_m)^{0.746}\ (D_x D_y)^{0.127}\ (Z)^{0.492} \qquad \{1\}$$

Where,

P	= Box Compression Strength, kN
P_m	= Edge Crush Test Strength, kN/m
D_x	= MD Flexural Stiffness, Nm
D_y	= CD Flexural Stiffness, Nm
Z	= Box Perimeter, m

Based on the powers in the McKee formula, it is recognized that edge crush strength plays a dominant role in determining box compression strength. Flexural stiffness and box perimeter play lesser roles.

Edge Crush

For two grade ranges, Whitsitt [3] has suggested equations for predicting edge crush from the ring crush of liner and medium used to manufacture corrugated board. These are given as,

ECT Grades 4.0-5.6 kN/m:

$$P_m = 0.80\ (2L + tM) + 2.10 \qquad \{2\}$$

ECT Grades 6.6-10.5 kN/m:

$$P_m = 1.27\ (2L + tM) - 1.05 \qquad \{3\}$$

Where,

L	= CD ring crush of the linerboard, kN/m
M	= CD ring crush of the medium, kN/m
t	= draw or take-up factor A-flute = 1.55 B-flute = 1.36 C-flute = 1.42

Whittsit also suggests an equation to predict edge crush from STFI compression strength,

$$P_m = 0.545\ (2L_s + tM_s) + 0.838 \qquad \{4\}$$

Where,

L_s = CD STFI compression strength of the linerboard, kN/m

M_s = CD STFI compression strength of the medium, kN/m

Flexural Stiffness

Based on Whittsit's work [3] we can get additional insight into edge crush by exploring how flexural stiffness is related to the properties of the linerboard and medium as well as the geometry of the combined board. Whittsit gives the following equations as approximations,

$$D_x = E_{xf}\, T\, H^2/2 \qquad \{5\}$$

$$D_y = E_{yf}\, T\, H^2/2 + E_{ym}\, I \qquad \{6\}$$

Where,

D_x, D_y	= Flexural stiffness in the MD and CD directions, Nm
E_{xf}, E_{yf}	= Young's modulus of the linerboard in the MD and CD directions, N/m^2
T	= Average linerboard thickness, m
H	= Combined board thickness, m
E_{zm}	= Young's modulus of the medium in the CD direction, N/m^2
I	= Moment of inertia of the flute, m^4/m

In these equations, MD flexural stiffness is primarily dependent on the Young's modulus of the linerboard and the combined board caliper. In the CD direction, the flexural stiffness is dependent on the Young's modulus of the linerboard and the medium as well as the moment of inertia of the flute.

Predicting Box Compression from Linerboard Properties

Assuming normal corrugating conditions, box compression strength, P, may be expressed as,

$$P = 0.3508\, (P_m)^{0.746}\, (D_x D_y)^{0.127}\, (Z)^{0.492} \qquad \{1\}$$

In our experiments we have produced linerboard that has different properties than conventional linerboard. We expect the following properties of the linerboard to have changed; L, E_{xf}, E_{yf}, and T. Since the linerboard thickness changes, so will H, the combined board caliper. Using Equations {1}, {2}, {5} and {6}, the change in P may be calculated from measured changes in L, E_{xf}, E_{yf}, T, and H. By differentiation of P, we obtain,

$$\Delta P = (\delta P/\delta L)\, \Delta L + (\delta P/\delta Exf)\, \Delta E_{xf} + (\delta P/\delta E_{yf})\, \Delta Eyf + (\delta P/\delta T)\, \Delta T + (\delta P/\delta H)\, \Delta H \qquad \{7\}$$

Taking the partial derivatives,

$$(\delta P/\delta L) = 1.1936\, \{P/P_m\} = \{1.1936/(0.80\, (2L+tM)+2.1)\}\, P \qquad \{8\}$$

$$(\delta P/\delta Exf) = 63.51\, \{TH^2/D_x\}\, P = \{127.02/E_{xf}\}\, P \qquad \{9\}$$

$$(\delta P/\delta E_{yf}) = 63.51\, \{TH^2/D_y\}\, P = 63.51\, \{TH^2/(E_{yf}(TH^2/2)+E_{ym}I)\}\, P \qquad \{10\}$$

$$(\delta P/\delta T) = \{0.254/T\}\, \{(E_{yf}H^2T+E_{ym}I)/(E_{yf}H^2T+2E_{ym}I)\}\, P \qquad \{11\}$$

$$(\delta P/\delta H) = 0.508\ \{(E_{yf}H^2T+E_{ym}I)/(E_{yf}H^3T+2E_{ym}HI)\}\ P \qquad \{12\}$$

Based on the linerboard data and the above equations, Table X was constructed.

Here we have assumed that the following properties were constant;

M	= 0.893 kN/m
E_{ym}	= 7.05×10^7 N/m^2
t	= 1.42
I	= 4.69×10^{-9} m^4/m, (estimated, see [4])

From Table X, the theory predicts that use of the impulse dried linerboard would yield a 0.066 kN increase in box compression strength compared to the case where the wet pressed linerboard was used. Most of the increase comes from the increase in ring crush with smaller increases from the Young's modulus terms. It is noted that the reduced linerboard thickness yields a negative contribution to box compression strength that is less than half of the magnitude of the ring crush term. It is also noted that, in actuality, we measured an increase in box compression strength of 0.19 kN. The discrepancy with the theory may result from the fact that the equations used are based on correlations. In any case, impulse drying yielded higher box compression strength because of the increase in ring crush (or STFI) and to a lesser extent from increases in Young's modulus of the linerboard.

REFERENCES

1. Orloff, D. I., Phelan, P. M., and Crouse, J. W., "Impulse Drying of Board Grades: Pilot Production Trials," Presented at the 1999 TAPPI Engineering/Process and Product Quality Conference, Aneheim, Sept. 12-16, 1999.

2. McKee, R. C., Gander, J. W., and Wachuta, J. R., "Compression Strength Formula for Corrugated Boxes," Paperboard Packaging 48(8):149 (1963).

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TABLES

Table I. Corrugating Conditions

Manufacturer	Langston
Type	XD
Width	2.21 m (87 inch)
Run Speed	121.9 m/min (400 ft/min)
Liner Width	0.762 m (30 inch)
Liner Basis Weight	161 g/m^2 (33 lb/msf)
Medium Width	0.759 m (29.875 inches)
Medium Type	40% non-sulfur - 60% OCC
Medium Basis Weight	126 g/m^2 (26 lb/msf)
Starch for Single-facer	modified pearl, 26% solids, 62.2°C (144°F) Gel Point
Starch for Double-backer	20% cooked, 80% raw, 26% solids, 64.4°C (148°F) Gel point
Anilox roll	1.378 lines/mm (35 lines/inch)

Table II. Printing Conditions

Manufacturer	Ward Machinery
Width	1.27 m (50 inch) x 2.79 m (110 inch)
Blank size	1.52 m (60 inch) x 0.69 m (27 inch)
Speed	80 kicks per minute
Ink	GCMI black (Borden Chemical Co.)
Anilox	6.299 lines/mm (160 lines/inch)

Table III. Die Cutting Conditions

Manufacturer	United Container Machinery Group
Size	1.27 m (50 inch)

Table IV. Identification of Liner and Medium Used

Paper Type	Third Press Type	Impulse Drying Temperature, °C	Calendering	Used In Case Number
Liner	Commercial			1
Liner	Impulse-Dried	246	no	2A
Liner	Impulse-Dried	246	no	2B
Liner	S.F. Wet Press		yes	3
Liner	Impulse-Dried	260	no	4
Liner	S.F. Wet Press		no	5
Liner	Impulse-Dried	246	yes	6
Medium	Commercial			1-6

Table V. Physical Properies of The Liner and Medium

Case	O.D. Basis Weight, g/m^2	Soft Caliper m	CD STFI Index, Nm/g	CD Ring Crush Index, Nm/g	Burst, KPa	Printed Side Emveco Roughness, Micro Deviation
1-Commercial Liner	147	210	21.6	12.0	574	184
2A-Impulse Dried Liner	150	218	19.4	11.9	539	85
2B-Impulse Dried Liner	150	218	19.4	11.9	539	85
3-S.F. Wet Pressed Liner	151	238	17.6	10.4	445	123
4-Impulse Dried Liner	150	218	19.4	11.9	521	81
5-S.F. Wet Pressed Liner	152	246	17.6	10.7	460	184
6-Impulse Dried Liner	150	208	19.2	11.8	533	69
(1-6) -Commercial Medium	115	185	16.6	7.7	243	n.m.

Table VI. Combined Board Properties

Case	Average Single-Face Pin Adhesion, N/m	Average Double-Back Pin Adhesion, N/m	Average Combined Caliper, mm	Average Edge Crush, kN/m
1-Commercial Liner	589	606	3.995	5.230
2A-Impulse Dried Liner	534	693	3.810	5.095
2B-Impulse Dried Liner	557	740	3.680	5.125
3-S.F. Wet Pressed Liner	660	729	3.725	4.640
4-Impulse Dried Liner	565	642	3.710	5.075
5-S.F. Wet Pressed Liner	735	677	3.765	4.635
6-Impulse Dried Liner	599	699	3.605	4.685

Table VII. Percent Change Compared to Wet Pressed Control

Case	Average Single-Face Pin Adhesion, & Change	Average Double-Face Pin Adhesion, % Change	Average Edge Crush, % Change
1-Commercial Liner			
2A-Impulse Dried Liner	-27.3	2.4	9.9
2B-Impulse Dried Liner	-24.2	9.3	10.6
3-S.F. Wet Pressed Liner			
4-Impulse Dried Liner	-23.1	-5.2	9.5
5-S.F. Wet Pressed Liner			
6-Impulse Dried Liner	-9.3	-4.1	1.0

Table VIII. Combined Board and Box Properties

Case	MD Flexural Stiffness, Nm	CD Flexural Stiffness, Nm	Top-to-Bot Box Compr. Peak Load, kN	End-to-End Box Compr. Peak Load, kN	Side-to-Side Box Compr. Peak Load, kN
1-Commercial Liner	9.83	4.97	1.99	1.27	1.62
2A-Impulse Dried Liner	8.70	4.32	2.00	1.36	1.64
2B-Impulse Dried Liner	9.12	3.92	2.04	1.17	1.54
3-S.F. Wet Pressed Liner	8.90	3.57	1.85	1.26	1.44
4-Impulse Dried Liner	9.82	4.30	2.14	1.41	1.76
5-S.F. Wet Pressed Liner	8.82	3.80	1.94	1.33	1.67
6-Impulse Dried Liner	8.80	4.04	Not avail.	Not avail	Not avail.

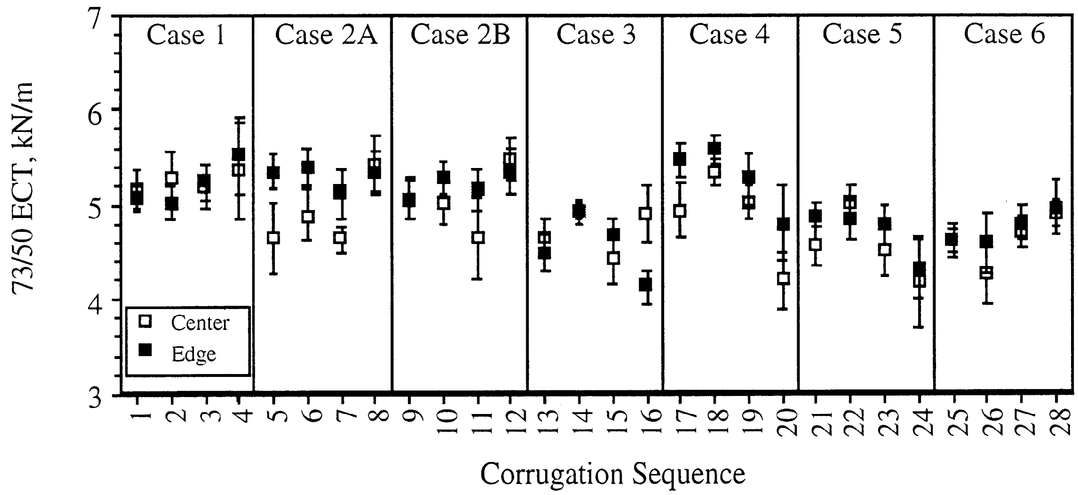
Table IX. Percent Change Compared to Wet Pressed Control

Case	MD Flexural Stiffness, % Change	CD Flexural Stiffness, % Change	Top-to-Bot Box Compr. Peak Load, % Change	End-to-End Box Compr. Peak Load, % Change	Side-to-Side Box Compr. Peak Load, % Change
1-Commercial Liner					
2A-Impulse Dried Liner	-1.36	13.68	3.09	2.25	-1.79
2B-Impulse Dried Liner	3.40	3.16	5.15	-12.03	-7.78
3-S.F. Wet Pressed Liner					
4-Impulse Dried Liner	11.34	13.16	10.31	6.01	5.39
5-S.F. Wet Pressed Liner					
6-Impulse Dried Liner	-1.12	13.17	Not avail.	Not avail.	Not avail.

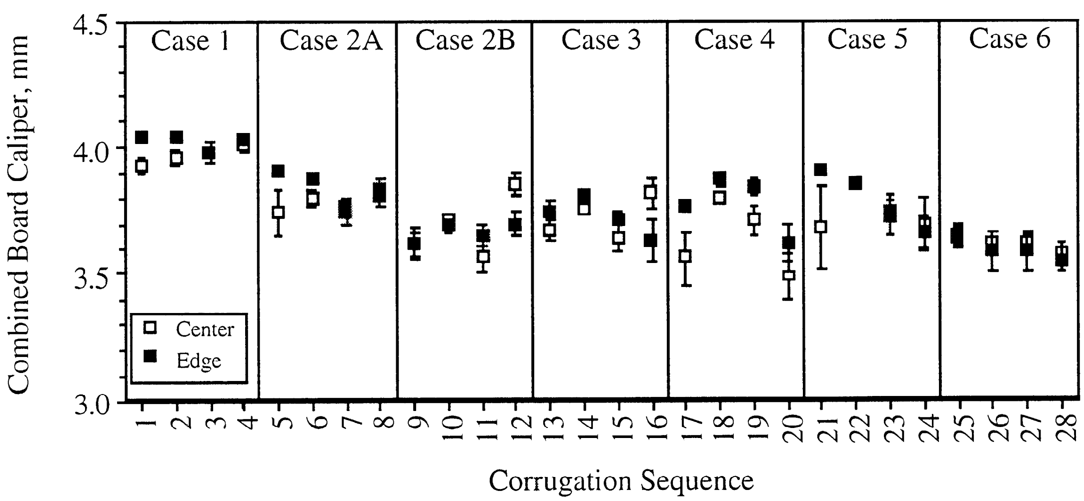
Table X. Measured and Predicted Change in Properties

Property		Wet Press Control (case 3)	Impulse Dried (case 2B)	Measured Change Δ(Property)
L,	kN/m	1.57	1.78	0.21
Exf,	N/m^2	360,500,000	375,700,000	15,200,000
Eyf,	N/m^2	132,300,000	146,400,000	14,100,000
T,	m	0.00024	0.00022	-0.00002
H,	m	0.00373	0.00368	-0.00005
P,	kN	1.85	2.04	0.19
$(\delta P/\delta L)\Delta L$,	kN	0.082		
$(\delta P/\delta E_{xf})\Delta E_{xf}$,	kN	0.010		
$(\delta P/\delta E_{yf})\Delta E_{yf}$,	kN	0.010		
$(\delta P/\delta T)\Delta T$,	kN	-0.027		
$(\delta P/\delta H)\Delta H$,	kN	-0.009		
Predicted ΔP,	kN	0.066		

FIGURES



<u>Figure 1.</u> Edge Crush Test of Corrugated Board (as Measured in the Center and on the Edges of the Board) Plotted Versus Corrugation Sequence.



<u>Figure 2.</u> Caliper Of Corrugated Board (as Measured in the Center and on the Edges of the Board) Plotted Versus Corrugation Sequence.

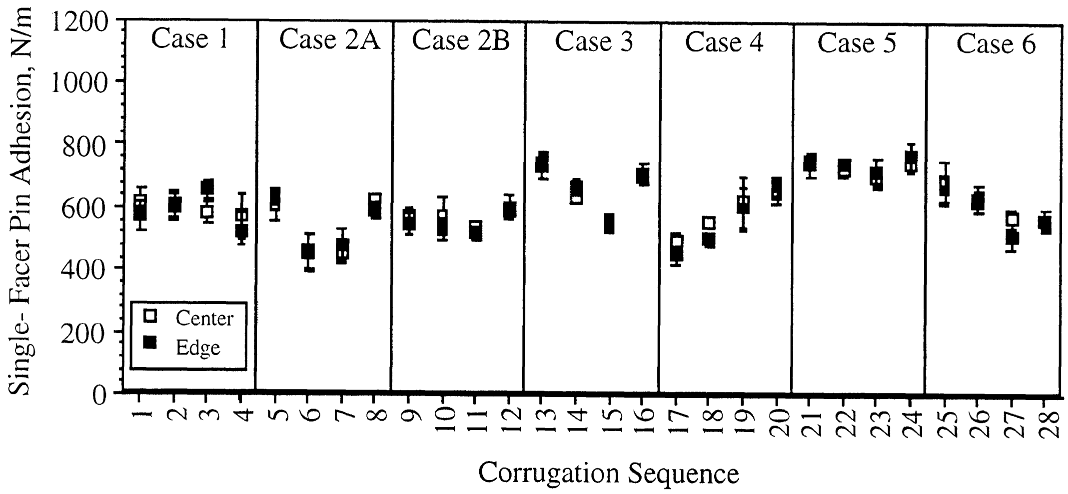


Figure 3. Single-Face Pin Adhesion of Corrugated Board (as Measured in the Center and on the Edges of the Board) Plotted versus Corrugation Sequence.

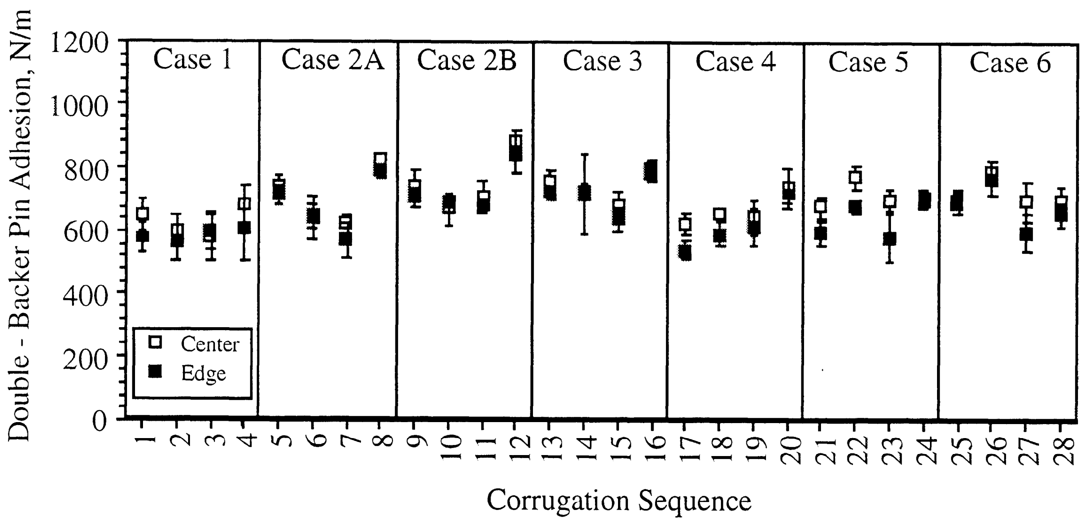


Figure 4. Double-Back Pin Adhesion of Corrugated Board (as Measured in the Center and on the Edges of the Board) Plotted versus Corrugation Sequence.

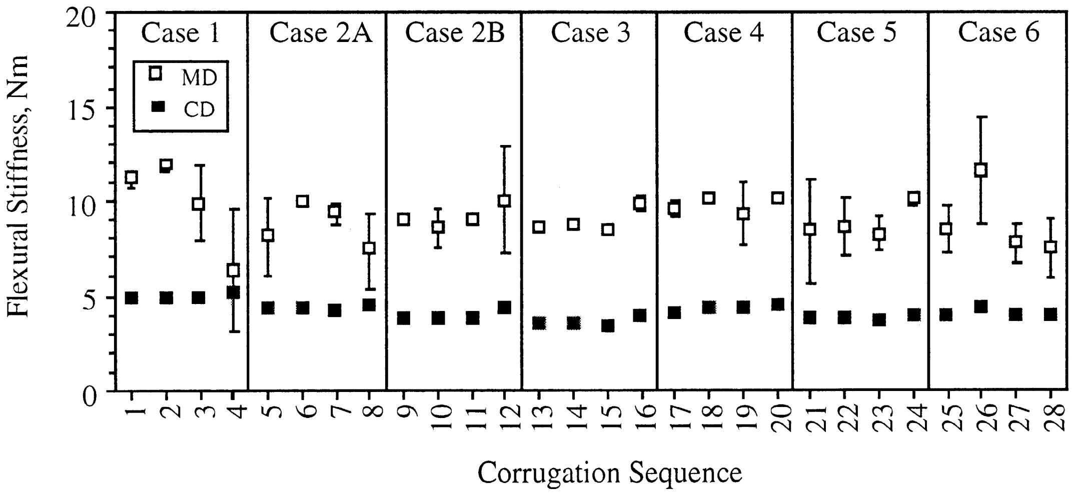


Figure 5. Flexural Stiffness of Corrugated Board (as Measured in MD and CD Directions) Plotted versus Corrugation Sequence.

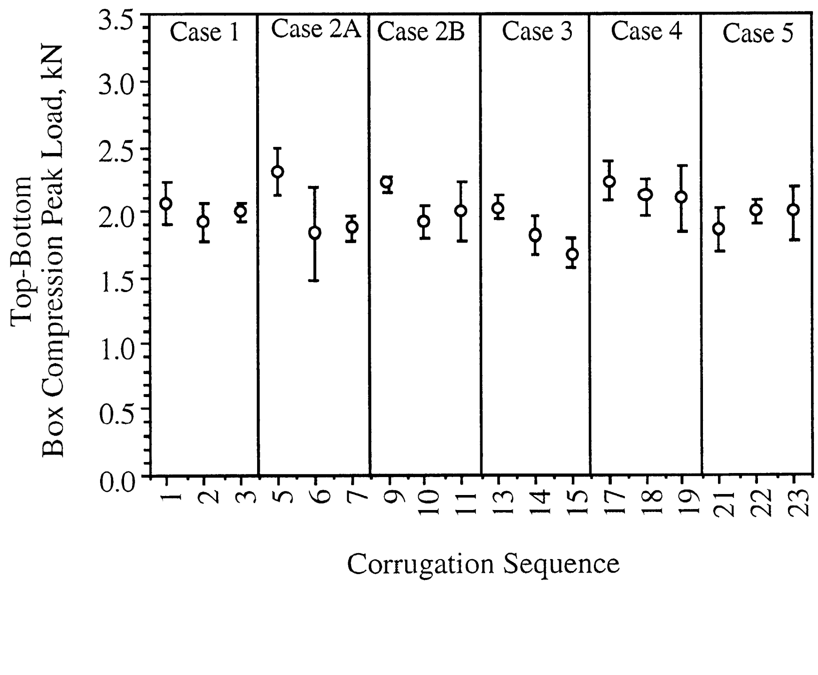


Figure 6. Top-To-Bottom Box Compression Peak Load Plotted versus Corrugation Sequence.

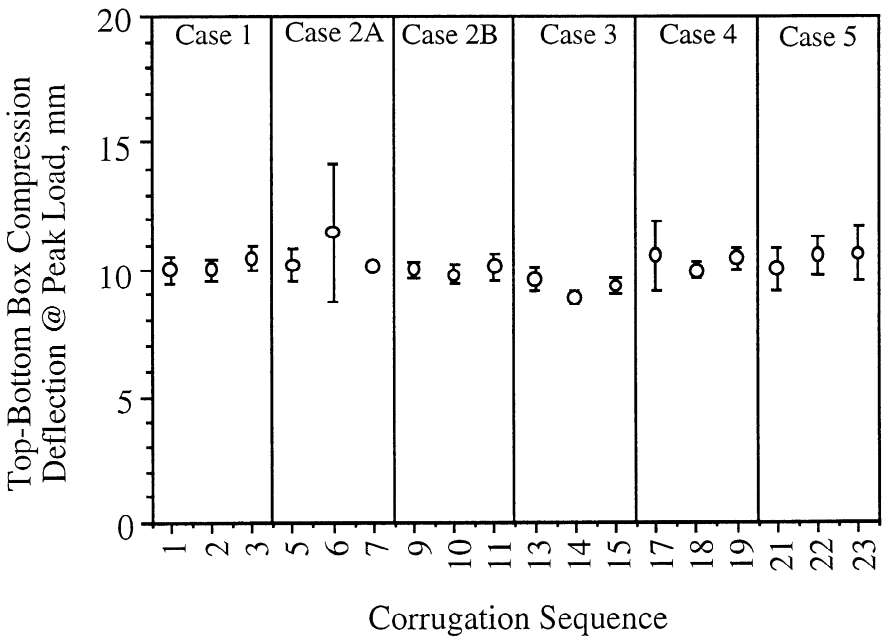


Figure 7. Top-To-Bottom Box Compression Deflection at Peak Load Plotted versus Corrugation Sequence.

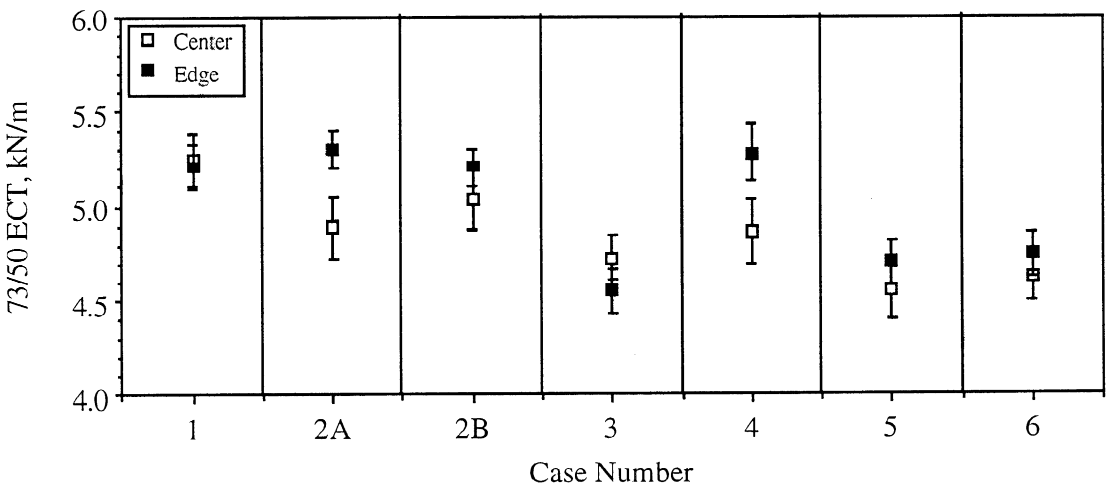


Figure 8. Edge Crush Test of Corrugated Board (as Measured in the Center and on the Edges of the Board) Plotted versus Corrugation Case Number.

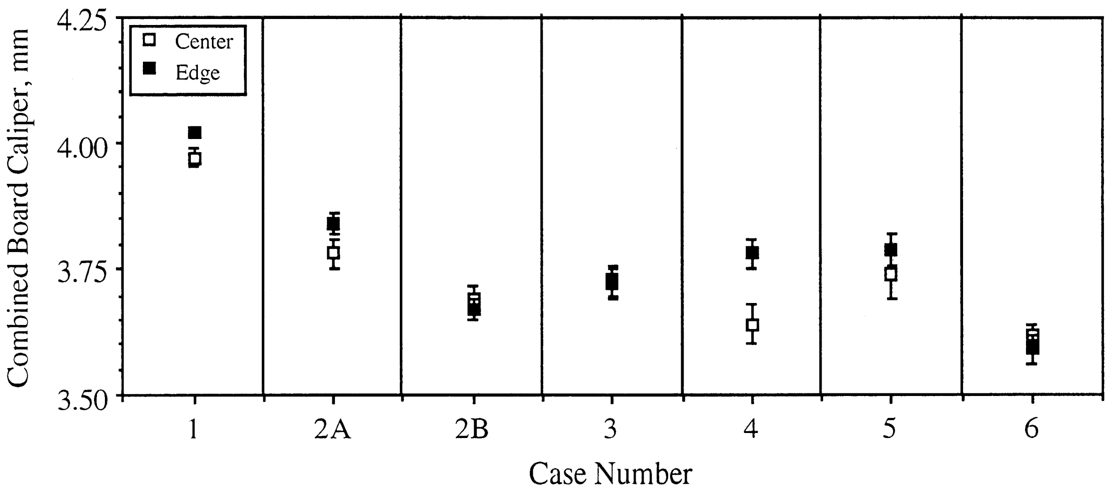


Figure 9. Caliper of Corrugated Board (as Measured in the Center and on the Edges of the Board) Plotted versus Corrugation Case Number.

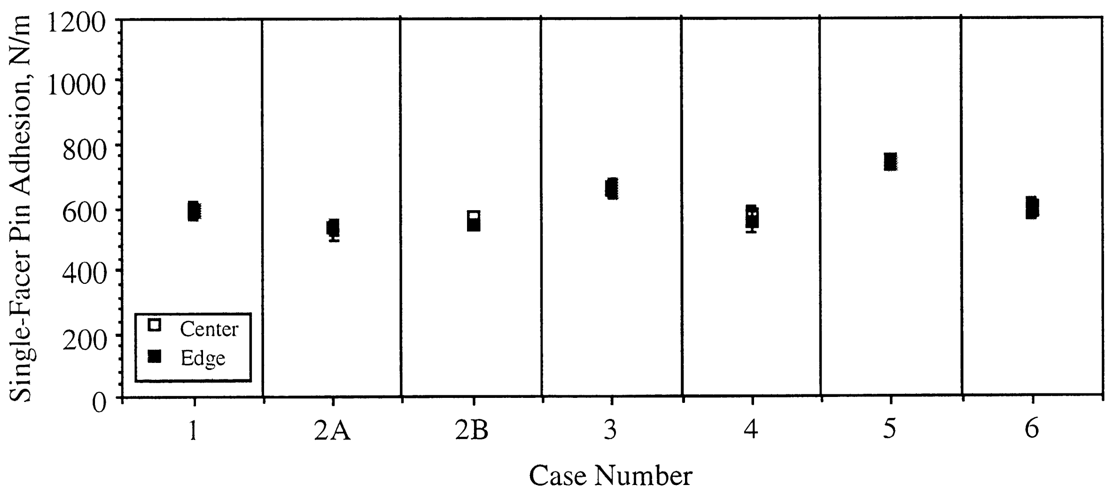


Figure 10. Single-Face Pin Adhesion of Corrugated Board (as Measured in the Center and on the Edges of the Board) Plotted versus Corrugation Case Number.

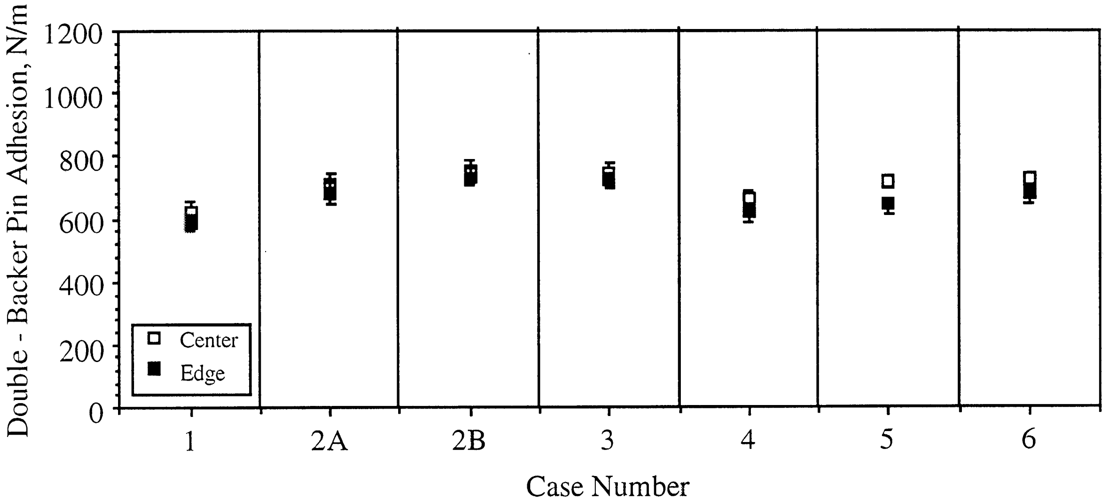


Figure 11. Double-Back Pin Adhesion of Corrugated Board (as Measured in the Center and on the Edges of the Board) Plotted versus Corrugation Case Number.

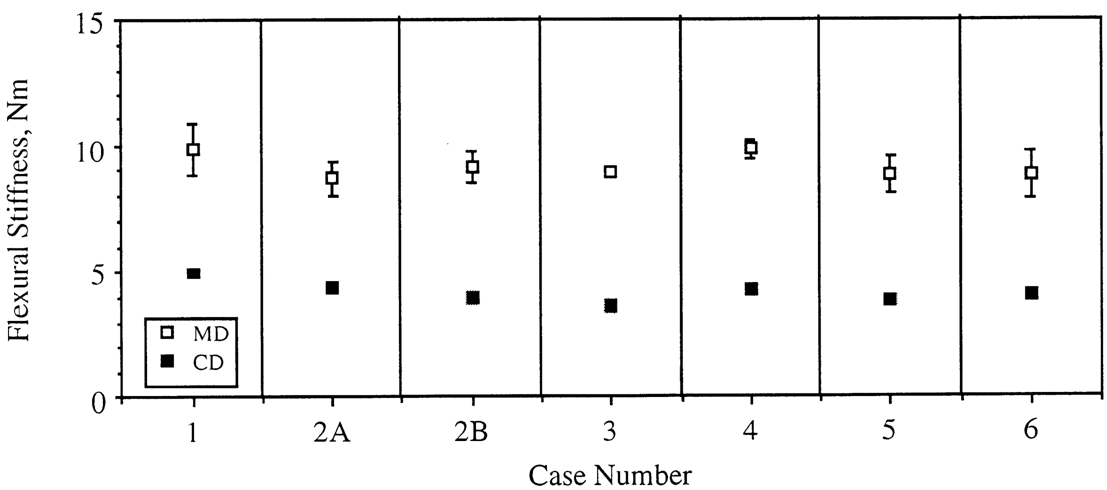


Figure 12. Flexural Stiffness of Corrugated Board (as Measured in MD and CD Directions) Plotted versus Corrugation Case Number.

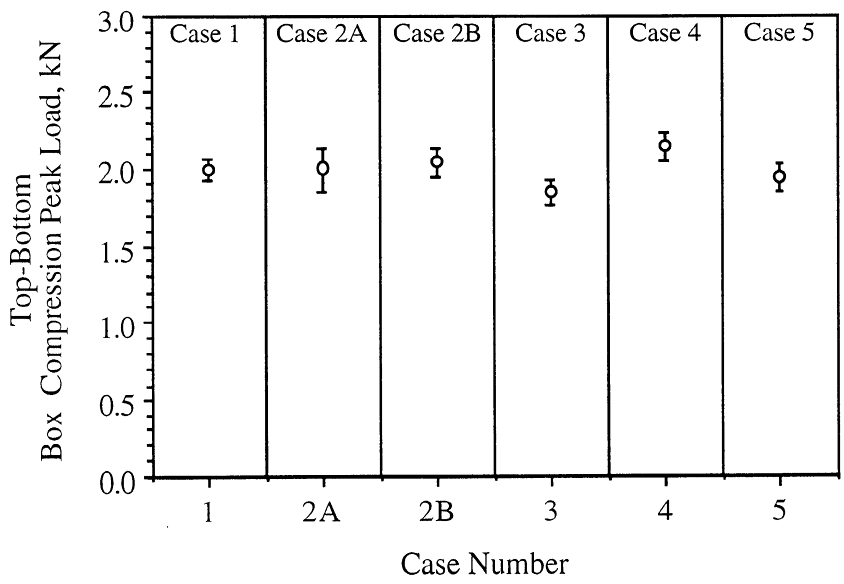


Figure 13. Top-To-Bottom Box Compression Peak Load Plotted versus Corrugation Case Number.

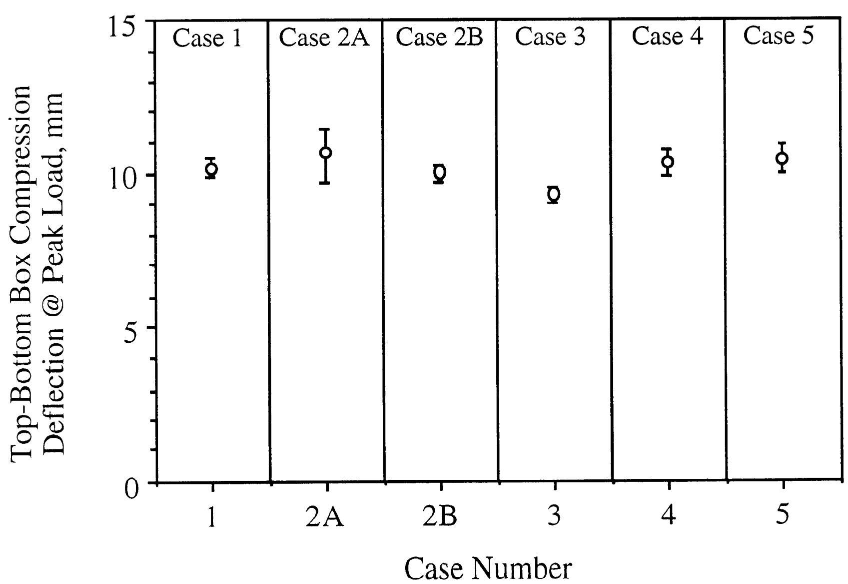


Figure 14. Top-To-Bottom Box Compression Deflection at Peak Load Plotted versus Corrugation Case Number.